IV. EMC Calibration System Design

The calibration system in its broad understanding is the set of tools and procedures to achieve the gain equalization and relative and absolute calibrations of all EMC and SMD channels, and continuous tracking of the gain variations with the subsequent corrections of the calibration constants. If appropriately designed, it can also help very much for continuous monitoring the EMC and SMD functioning, for the fast and unambiguous detection of the malfunctioning channels and their components.

In this section, the designs and characteristics of all EMC and SMD calibration subsystems are presented along with the task and achievable accuracy for each particular tool.

IV.1 Requirements

The most stringent requirements to the equalization of signals from the EMC towers come from the lowest-level fast L0-trigger. The well equalized towers are those having equal responses ("electric signals") to the electron-photon hits of equal energy, *E*, or equal transverse energy, $E_T = E \cdot \sin\theta$, etc.[1] The usual EMC contribution to the fast trigger is to select events with a high local and/or global energy deposits[2] above the chosen L0-trigger's threshold(s). Along with the other factors, the "sharpness" of thresholds for this kind of "High-P_T" triggers depends on how well the signals from the EMC towers have been equalized. On the other hand, due to the finite EMC resolution which also contributes to the widening of the thresholds, it does not make sense clearly to fight too hard for the tower's equalization much better than the intrinsic EMC energy resolution, σ_E / E. In the range of interest for L0's E_T-thresholds in STAR[3] from ~3-5 to 10 GeV, the expected intrinsic resolution is $\sigma_E / E \approx$ 5-10%. This means that the equalization of the EMC towers to the level of ~3-4% would be sufficient in the E_T -interval of ~3-10 GeV, particularly early in the program.

Acceptable statistical uncertainties of the EMC tower's <u>relative</u> calibration, i.e. for the statistical error of the knowledge of the calibration coefficient for every single tower relative to some "base gain" is, to some extent, equivalent to the "tower's equalization" problem but for the data analysis rather than L0-trigger because the statistical errors of the calibration coefficients will effectively contribute to the "final" EMC energy resolution. The difference is that, while the equalization of electric signals is important in a rather limited energy range of L0-trigger thresholds, the requirements to the relative calibration are relevant to the entire energy interval of interest for STAR from

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[1] The polar angle $\theta = 2\arctan(e^{-\eta})$.

[2] That is either E or E_T or both.

[3] D. Underwood, STAR Note 180, 1994; B. Hubner, G. D. Westfall, A. M. Vander Molen, STAR Notes 275 and 276, 1996.

~0.5-1 to ~50-60 GeV. At the energies below ~10 GeV, the knowledge of the calibration coefficients at the same statistical uncertainty of ~3-4% as for the signal's equalization would be sufficient. The simulations with GSTAR[4] have shown that, at the energies above 20-30 GeV, the intrinsic EMC energy resolution is almost constant and equal to ~3%. With this resolution, for example, the width (RMS) of Z^0-peak, $\Delta M_Z/M_Z$, in e^+e^--decay mode, including its natural width, will be 3.5%. For a twice worse EMC resolution of ~6%, the width of Z^0-peak would increase by a factor of about 1.5 to $\Delta M_Z/M_Z = 5\%$. The summary of these considerations is that the requirement for the accuracy of relative calibrations of each single tower of no worse than 3-4% seems to be valid for the entire energy range from ~0.5-1 to ~50-60 GeV. Of course, over time, one can and will do better, but the point to note is that relative calibration coefficients with this level uncertainty will not significantly impact the physics program.

The most restrictive requirements for the <u>absolute</u> EMC calibration in STAR arise from the measurements of the steeply falling with P_T differential cross sections. Fits to the SPS data[5] for inclusive direct-γ and π^o-spectra at $P_T > 10$ GeV/c give the dependence of $d\sigma / dP_T \propto P_T^{-(5-5.5)}$. The ISR measured spectra[6] at lower P_T's from ~4 GeV/c and up fall even more sharply, $\propto P_T^{-(6-8)}$. To measure this kind of differential cross sections with the systematic errors of no more than ~10-20%, the EMC absolute scale in the region of interest has to be known at the accuracy of ~2%.

The requirements on tracking the variation of tower gains over time are directly related to the consideration above. Tracking the variation of the mean gain for the entire EMC or quite large patches[7] has to be done at the accuracy of the absolute energy scale, i.e. no worse than ~2%. The statistical errors for tracking the gain variations for each single tower can be allowed to be large, ~3-4% as for the relative calibration and equalization.

<u>IV.2 Overview of Calibration Methods</u>

IV.2.1 EMC

The calibration and monitoring systems and methods for the EMC towers are generally a superset of those for (upgrade) pre-shower and shower maximum detector (SMD). The main goal of EMC calibration is to establish the absolute energy scale of each tower to the precision discussed above. However, a full calibration using physics events in STAR may occur on time scales which are long compared to a physics run. It is

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[4] GSTAR is the STAR configured version of GEANT.

[5] C. Albajar, et al (UA1), Phys. Lett. **B209** (1988) 385; J. A. Appel, et al (UA2), Phys. Lett. **B176** (1986) 239.

[6] E. Anassontzis, et al, Z. Phys, **C13** (1982) 277.

[7] For example, 40 towers of each single EMC module or η-ring, consisting of 120 towers.

therefore important to monitor the stability of the entire optical system chain including phototubes on shorter time scales. For example, a scan of the towers with radioactive sources may occur only at construction in conjunction with cosmic ray tests or once per year or less after installation. The radioactive source method calibrates the overall system, scintillator, fiber, and phototube, but it occurs very infrequently. The observation of minimum ionizing particles either while running or between runs, like the radioactive source, tests the whole optical system, but like cosmic rays, it irradiates all tiles simultaneously. The light diodes, on the other hand, which will feed into the cookies on the phototubes via fibers can monitor the phototubes alone for each run. This independence is useful, because the light output of the scintillator is expected to increase by about 5% when the magnetic field is on, the light transmission through fibers could change, etc. This can be monitored by comparing the LED and MIP calibrations.

The following techniques have been found to be effective and cost-effective in similar calorimeters in other experiments. We will use them in STAR EMC:

1) Calibration of a sample of modules in a test beam of electrons and hadrons.
2) Cosmic ray testing and calibration at the time of construction.
3) Penetrating charged particles close to minimum ionizing in the testbeam and online during STAR running
4) LED light flashers (green) for the phototubes. These are capable of establishing the (absolute) PMT gains to a fraction of a percent. (See Bencheikh et al., NIM A315 (1992) 349.)
5) Radioactive sources near shower max depth at the time of cosmic ray testing (module construction)and/or periodically thereafter
6) Conversion electrons
7) 2 body decays
8) Electronics / Charge injection

IV.2.2 SMD

The calibration of the shower maximum detector poses different issues. We must find the absolute calibration in known conditions, and then monitor the gas gain with temperature and atmospheric pressure and high voltage variations. We will calibrate the electronics separately. The gas gain must be normalized to electron showers of known energy in the calorimeter with known gas mixture, high voltage, pressure, temperature and magnetic field.

For SMD, the objectives are to establish the energy scale relative the EMC towers, to establish a scale at particular values of atmospheric pressure, HV, etc so that gain can be tracked; and to calibrate the channel to channel variation of the 36k channels caused by different strip to wire capacitances and different transmission lines. Clean cosmic ray signals from the SMD require that the HV (and gain) be increased, so this is not completely adequate for the absolute scale, but will provide the channel to channel gain variation measurement. The EMC methods of test beam, MIPS, conversion electrons, and two body decays provide the rest of the calibration.

IV.3 Some General Features of our General Philosophy

In the long run the absolute calibration comes from physics events such as J/_ decays, conversion electrons, etc. Electrons are used to tie the EMC calibration of each tower to measurements of magnetic field and track curvature. An abundant source of electrons is from conversions of gammas from _^{o}'s in the beam pipe and the SVT. This material constitutes about 5% of a radiation length. The resolution of the calorimeter and the tracking are comparable at about 15 GeV if the vertex is used in fitting the track. Above this energy, the means of the E vs. p distributions can be found very well if a number of events are used.

However for EMC calibration, using these electrons requires a rather long time (on the order of a year) to obtain sufficient statistics and do the required analysis to have each tower calibrated in a sufficiently wide energy range. Therefore several other "indirect" methods will be used to reasonably accurately set of tower gains and obtain the initial calibration constant immediately after a module installation and/or during a few first days or even hours of running RHIC. In the rest of this chapter, we'll concentrate on the description and evaluation these of various "indirect" techniques which will be used in STAR EMC for the tower equalization, calibration, and continuous tracking the gains.

As a general principle, it is very useful to cross-calibrate test beam data, cosmic ray response, radioactive source response, response to minimum ionizing hadrons and LED response, fully, on a few calorimeter modules. This method allows reasonable absolute initial calibration of similar modules with cosmic rays and/or radioactive sources and, most importantly, allows the establishment of the relation of this calibration to those methods which can be more readily applied in beam (MIP, LED). The initial calibration of the entire calorimeter can be made traceable to electron results in the test beam by this approach. Of course, the test beam will also pursue the goal of accumulating valuable information about the electromagnetic shower shape in the SMD and shower sharing between the adjacent EMC towers. This information will then be used in the data analysis for reconstructing the particle hits in the EMC and SMD.

IV.4 Practical Implementation

The practical implementation of EMC calibration technique will include several steps.

An exposure of several EMC modules to the test beam composed of electrons and other charged particles will serve as a basis for all "indirect" calibration approaches. In the test-beam runs, the ratios of the EMC responses to electron and minimum-ionizing particles, mostly penetrating hadrons, (MIP) hits (*e*/MIP-ratios) will be measured for the towers at various η as well as the ratios of signals from particle hits to the DC current from the radioactive source (*e*/RS-ratios). These measurements will be made with PMT gains that have been established using the LED system. After an exposed module is installed in the STAR detector, setting the gains for its tower will be done using the LED system and setting the DC currents from radioactive source to the desirable level. In the following discussion we show that beginning from this initial "calibration", a few days of RHIC running with Au+Au is required to establish the calibration coefficients in every tower to an accuracy of a few % from the measurements of MIP-hits. (see Sec. IV.5.2 for details).

For modules untested in the electron test-beam, the *e*/MIP- and *e*/RS-ratios are expected to be very close to those of the tested ones. Therefore, the procedures described above can also be used to set the tower's gains and to measure the calibration coefficients for these modules as well. The main source of the error of the initial calibration coefficients for untested modules is expected from variations of the relative light output from tile-to-tile in otherwise identical towers. On the base of simulations, the design limit of the light yield variation is set to be no more than $\pm 10\%$ (RMS) on a tile by tile basis. With this requirement and after the tower's equalization, using radioactive source or MIP-hits, the deviation of the calibration coefficients in the individual towers from the mean values is not expected to exceed ~2-4% (RMS) in the entire energy range of interest from ~1 to 50-60 GeV (see Fig.IV.4.1[8]).

To make sure these optical design tolerances are maintained, various quality control procedures have been developed for each step of the manufacturing and assembling the EMC and SMD modules. They are described in details in Sec.II of this document.

After the final assembly, every single module will undergo at least three times, quality assurance tests designed to spot broken Light Collecting and Transport Units (LCTU), i.e. broken tile-fiber assemblies, fibers, and/or fiber connectors. This will be done the first time at the manufacturing site just after the module is built; second time, after it has been shipped to BNL, before the installation; and third time, after the module is installed in STAR. The technique being used for these tests is described in Sec. IV.5.4.

It should be underlined that the identification of the missing LCTU's in the towers is an important issue. One or two missing LCTUs can change the tower's light output from an electron-photon hit by up to ~20-30%, depending on the location of the "missing tiles" within the tower (Fig.IV.4.2). The drop of the light output by itself is actually not a big problem. Using the calibration techniques described above, the tower's "mean" calibration coefficient at any particular energy. However, these corrections don't put the end of the story. Due to the "missing tile(s)", the tower's signal functional dependence on the energy of electron-photon hits becomes essentially "individual" and can significantly differ from the "canonical" EMC's "signal-energy" characteristic. Even after correcting the damaged tower's calibration constant(s) at any single energy or in the energy range, the residual deviation of the tower's sensitivity from the "canonical" one beyond this range can be as high as ~10-20% (Fig.IV.2.2). The worst things is that these deviations, even their sign, are essentially unpredictable without an exact knowledge of the position of the missing LCTU in the stack. For a known position of the damaged LCTU in the stack and after the tower "equalization", simulations[9] or, even better,

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[8] See for details: A. A. Derevschikov and O. D. Tsai, SN216 (1995).

[9] All currently available simulation tools (GEANT, EGS, …) quite satisfactory describe the longitudinal development of electron-photon showers which is virtually the only shower's property relevant to correcting the "missing-tile effect".

experimental data on the effect of “missing tiles”[10] can be used to reduce down the uncertainty of the signal-energy dependence to the acceptable ~3-4% level.

At the manufacturing site, each module will simultaneously be exposed to cosmic rays and radioactive source. The ratios of the cosmic ray signals and the DC currents from the radioactive source (CR/RS-ratios) will be measured for each tower. These measurements will provide some additional information which then can be used to introduce individual module corrections to the calibration constants for the radioactive source calibrations. For a day, few thousands of cosmic rays, crossing all 21 tiles of a single tower, can be accumulated. The detailed description of the setup for cosmic ray measurements is given in Sec. IV.5.5 of this documents.

During the RHIC beam runs, the tracking the variation of the EMC channel’s gains on the daily and hourly basis will be performed using MIP-hits in the EMC from the colliding beams. The continuous tracking the stability of PMTs and the electric parts of the chains will be accomplished using green LEDs and charge injection technique.

IV.5 Calibration methods and system’s designs and integration

IV.5.1 Test Beam

For the first Module, the test beam will provide absolute calibration of towers within 3% from 0.5 to 8 GeV without relying on other STAR detectors. This can later be transferred to other EMC modules. Calibration is be done in the test beam, and then carried to other modules with Sources and Cosmic rays and minimum ionizing particle signals in order to establish absolute scale. The scale of the individual module calibrated in the test beam can also be carried by LED.

The test beam can establish the correlation between SMD and EMC signals vs. energy and establish that both tower and SMD maximum signals are within the range of the electronics (both high and low end).

IV.5.2 Penetrating Charged Particles (MIP)

Many charged hadrons (along with small admixtures of electrons and muons) will be produced in every collision at RHIC. In the central region covered by the STAR Barrel EMC (BEMC), these are mostly pions. When striking the BEMC, a significant fraction (~30-40%) of high energy charged hadrons do not deposit a large amount of energy via nuclear interactions, instead depositing ~20-25 MeV of energy in the calorimeter’s 21 scintillator layers due largely to electromagnetic ionization. In this document, we will loosely call these hadrons (and muons too) as “Minimum Ionizing Particles” (MIP) producing “MIP-hits” in the BEMC towers.

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[10] For the “frozen” EMC tower’s design, it would be very desirable (while not absolutely necessary) to measure at the external beam the “signal-energy” dependencies for each tower in the entire energy range of interest in STAR from ~0.5 to ~50-60 GeV. This experimental study with one or two modules needs to be done just once for the entire STAR EMC’s life-time. This experiment would also be the best time for measuring the “missing-tile effect” along with its η-dependence.

For the relativistic particles, the position of "MIP-peak" is nearly independent of momentum and particle species. This, along with the high yield of charged hadrons, makes it attractive to explore the feasibility of using high energy MIPs for the equalization, calibration, and continuous tracking the stability of the BEMC tower's gains.

The calibration scheme using MIP-hits includes two stages. At the first stage, a sample of BEMC modules is exposed to the external beam, for example, at AGS. The test beam at AGS is a mixture of all kind negative particles of a chosen momentum, selected in the range from 0.3-0.5 to 7-8 GeV/c. The composition of the beam are mainly π mesons and other hadrons with some fraction of electrons and muons. Therefore the ratios of each tower's responses to electron's and MIP's hits (*e*/MIP-ratios) of various momenta are measured simultaneously[11]. This makes the measurements of these ratios completely independent of the PMT's and QDC's gains, possible attenuation and distortion of signals in cables, delay lines, etc., i.e. in the equipment which might be necessary for the test run but won't be present or will be different in the STAR detector, and vice versa.

At the second stage, after the modules have been installed in their places in the BEMC, and the RHIC accelerator is producing collisions, the samples of MIP-hits of the particle composition and momenta as close as possible to those in the test beam are accumulated for each tower, and the positions of MIP-peaks are measured. This step essentially completes the procedure of transferring beam-test results to STAR. For those towers exposed to the test beam, their response to electron hits[12] can immediately be predicted, using the known *e*/MIP-ratios that have been measured at the test-beam stage. For non-tested modules, these ratios are expected to be close to those of the tested ones.

It's obvious, of course, that the compositions of MIPs in the test beam and in STAR at RHIC can never be exactly the same and quite often won't be exactly known. To accumulate a sufficient statistics for a reasonably short time, the momentum range of the selected MIPs in STAR cannot be made as narrow as it was in the test beam. Moreover, the STAR 's 5 kGs strong magnetic field may noticeably change the *e*/MIP-ratios compared to those measured with the external beam. These are the main sources of the systematic errors, which set the limits to the achievable accuracy for the absolute calibrations of the STAR BEMC, using MIP-hits.

The expected characteristics of *pp*- and heavy-ion events at RHIC are the basis for evaluating the systematic errors. It's clear that the low-P_T charged particles are useless because their deflection in the STAR's magnetic field causes them to enter the BEMC at large angles. Only a small fraction of these particles pass through all 21 scintillator tiles of a single tower. On the other hand, if a chosen P_T-threshold were too

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[11] Or almost simultaneously for electrons and MIPs of different momenta.

[12] … of the momenta actually used in the test-beam run …

high, the useful event rate would be too low due to the steep drop of the particle yield as P_T increases. The simple estimates suggest MIPs of P_T's just above ~ 1 GeV/c as the best compromise between yield and utility. In the magnetic field of 5 kGs, the trajectories of no fewer than ~50-60% of directly produced[13] charged particles with $P_T \geq 1$ GeV/c will pass through all 21 tiles of a single BEMC tower. For a particle of this transverse momentum, the deflection in the magnetic field increases its path within a tower by no more than ~1-1.5%. As an additional benefit, particles of this momentum are available at the AGS test-beam.

In *pp* collisions, the CTB can select events with at least one charged particle within its acceptance[14]. For Au-Au collisions we consider two sets of data: all events without any additional selection criteria, and low multiplicity events with $1 < N_{CTB} < 100$. In every single event, the potential "target-towers" for MIP calibrations are those, struck by *at least one* "high-P_T" charged particle of $P_T > 1$ GeV/c, which are called in this section "*h*-towers", or their even "cleaner" subset of "*1h*-towers", which are struck by *one and only one* charged particle[15] of *any* P_T. These towers can easily be pointed out in every single event, using the rich tracking capabilities of the STAR detector. The mean numbers of "*h*-" and "*1h*-towers" per event are each of order 1.

A comprehensive study of the BEMC absolute calibration based on MIP-hits has been undertaken, using simulations and available experimental data. The various systematic shifts of MIP-peak positions due to variations of MIP's composition, momentum, and admixture of neutrals have been estimated as well as the effects due to STAR's magnetic field. GEANT simulated distributions of energy deposits from 1, 1.5, and 2 GeV/c pions in the BEMC[16] have been studied and conpared with the experimental distributions obtained from exposing the STAR BEMC prototype to the AGS test-beam. From both the simulations as well as the experimental data it follows that the variation of MIP-peak's position[17] within 1-2 GeV/c momentum range is just about $\pm$ (0.5-1.5)%.

The MIP-peaks in *1h*-towers with one charged particle at $P_T > 1$ GeV/c have also been simulated for the STAR-at-RHIC. According to these simulations, the shifts of MIP-peak's positions in STAR-at-RHIC won't exceed ~1.5-2% compared to 1-2 GeV/c pions used in the test beam. With the STAR magnetic field "on", the most probable energy deposits by MIPs increase by only ~1-1.5% due to the change in the energy spectrum. Additionally, in the presence of the magnetic field there is a geometric effect

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[13] … and noninteracting strongly in the BEMC!

[14] Only charged particles with $P_T > 0.15$ GeV/c are counted because lower P_T's will effectively be wiped out by the STAR magnetic field and won't reach the CTB and BEMC (see Fig. IV.4.2.1).

[15] … which would actually be the "high-P_T" one.

[16] With no magnetic field.

[17] Parameter "P2". For the sake of simplicity, the "Gaussian + polynomial" fits have been used here. Fits with some other resonable functions provided the similar results.

coming from the curvature of the particle tracks. This effect also produces a shift on the order of a few percent. Due to purely geometric nature of this effect, it can also easily be accounted and corrections introduced.

From the consideration above, calibrations using minimum ionizing particles seems to be a good candidate to calibrate the STAR BEMC to systematic uncertainties of order ~2-3%. To reach comparable or lower statistical errors, the sufficient number of useful hits from noninteracting charged high-P_T particles needs to be accumulated in each tower. The width of MIP-peaks[18] not accounting the photoelectron statistics, is about ~10%. For the mean light yield from a single BEMC tiles at the lowest design limit of 2 phe/MIP, the estimated width of the MIP-peak would be ~17-20%.

The following table gives the running time required to achieve the indicated statistical accuracy on the MIP peak position.

	20%	10%	5%	2%	1%
pp	23 min	1.5 hr	6 hr	38 hr	6.3 day
AuAu Peripheral	5 min	20 min	1.3 hr	8.3 hr	2.5 day
AuAu Min Bias	1 min	3 min	12 min	1.2 hr	5 hr

To minimize a time for accumulation this number of hits, the L3-trigger tracking has to be exploited to select events with high-P_T tracks pointing out to the BEMC's towers, and to reconstruct the parameters of these tracks. Otherwise, the raw data from the entire TPC needs to be recorded, and the event rate would be unacceptably low. By design, the input L3 event rate in STAR can be as high as 100 Hz. It's worth noting that the above estimates are for the time that required to get every BEMC tower calibrated. After the towers are "equalized" to a few percents ,however, the tracking of the mean gain variations for a patch, consisting of N_{tw} towers, will take by a factor of N_{tw} less time compared to what was necessary to calibrate every single tower with the same statistical uncertainties.

To summarize, the above study has shown that, using MIP-hits, the equalization and transfer of the absolute scale from the test beam calibrations can be done to an accuracy ~$\pm$ 1-1.5% in a reasonable amount of time[19] for the entire EMC. MIP-hits are also an effective tool for continuously tracking the variations of the EMC tower's gains to the level of at least ~$\pm$ 1-1.5% a day, virtually without interference to the running in parallel STAR's main physics program. This method does not rely on simulations for anything other than geometric and some other small corrections, and also estimates of systematic errors: it directly transfers measured test beam responses to operations at RHIC.

[18] Ratios "P3/P2" of the "Gaussian + polynomial" fits.

[19] In heavy-ion collisions.

Further studies, not reported here, show that to achieve the accuracy level of the absolute calibrations above, it is not necessary to strictly control and limit the momentum range of useful MIP-hits, although the rich STAR's tracking capabilities allow us to do this. The limitation of this method (or any other indirect[20] method) is due to the construction tolerances of the calorimeter. Individual tower variations of light yield from tile-to-tile introduce nonliniarities in the energy responses due to the development of mean shower depth with energy. These will always limit our ability to apply the test-beam calibration of a few modules over a restricted energy range to the nontested ones to about $\pm$ 2%[21]. MIP calibration allows us to reach this theoretical limit in less than one day of RHIC, running heavy-ion collisions.

IV.5.3 LED

A system of green LED's can provide a precise (fraction of a percent) calibration of the photomultiplier gain . (See Bencheikh et al., NIM A315 (1992) 349.)

An LED box with 15 LEDs , each driving 7 fibers, will be mounted in each PMT box. This will provide signals to the 80 PMT tubes (and 5 pre-shower tubes if upgraded), with cross correlations to be used in case an LED fails. LED signals (with temperature corrections to the LEDs done offline) can be measured hourly.

To take an LED event, EMC must request a calibration trigger from STAR, and then flash the appropriate LED in synch with the event that the trigger issues to EMC. This will depend upon the STAR trigger issuing a calibration trigger a fixed number of rhic clocks after the request is made or else sending some kind of pre-trigger signal. The LED signal will be at about 3 GeV in each phototube (within a factor of 2).

IV.5.4 light reflection technique for testing fibers

An important requirement of the calibration techniques which rely on light from the scintillators is that the optical pathway from each scintillator layer to the PMT be functioning. In the presence of broken fibers, different calibration techniques can produce vastly different results. Consequently, we here discuss the diagnostic techniques used to study the condition of the entire optical pathway for each tower. These same techniques, are used during calorimeter construction as quality assurance measures.

The principle of testing the fibers is simple, namely to shine a light into the fiber and measure the amplitude and timing of the reflection from the aluminization at the far end (which is in the tile). This is similar to techniques used for testing telephone lines.

To do this in practice, we need to handle very large numbers of fibers in a short time with simple and rugged equipment. There are two mass connectors on each fiber path, one on the side of the module, and one in the side of the phototube box. The testing

[20] "Direct" methods are those, using for calibrations electron and photon hits themselves.

[21] To make it clear, this limit has no any relations to the tracking the stability.

device will have 10 independent channels to test all 10 fibers in a connector simultaneously. To shine light down the same path over which the reflection is measured, a directional coupler is needed. Unfortunately, the directional couplers made of two fibers used for fiber optic gyroscopes, etc, do not work with large, .8 to 1 mm fibers. We therefor need to use half silvered mirrors. Some experiment will be needed to determine the optimum lens system to obtain the best measurements with LED or laser.

The timing will help to isolate the part of the reflection from the end of the fiber. There are other reflections of about 7% of the light at each connection interface. The timing needed is to distinguish a 35 ns round trip from a 45 ns round trip.

The measurements will be analyzed on a PC and the results will go into a data base for future reference.

IV.5.5 Cosmic ray measurements

The cosmic ray test stand at RHIC (and the assembly sites) provides a calibration of each module before installation and in particular a way to set the High Voltages which is separate from the individual phototube calibrations done on the bench. This is essential for operation of the trigger. It also provides a check of performance after shipping. The testing will be done in a small building near the STAR assembly building. This building has floor space and roll up doors for unloading modules.

The test at BNL will take only a few days per module, including connecting temporary fiber assemblies and electronics and light-tightening. After allowing for fiducial cuts, angular cuts, and momentum hardening with absorbers, we expect to have 50 events per tower per day in a module of 40 towers. With 30% resolution on signals from charged tracks which are slightly more than minimum ionizing, this will give a 4% calibration one day.

The cosmic ray test stand set-up will be assembled primarily of existing parts. Large area drift chambers with their associated electronics are available from Argonne. Trigger scintillation counters are available which would cover the module on bottom and top. Data acquisition will be through CAMAC with an inexpensive controller interfaced directly to a PC. Triggered electronics, in contrast to the clocked electronics to be used in RHIC running, will be more efficient for the cosmic ray testing.

Cross calibration with radioactive source will be done while the module is in the cosmic ray test stand. The cosmic rays sample all the scintillator layers equally, while the source deposits energy strongly in the adjacent layers near layer 7, and about a factor of 2 less in each succeeding layer away. Any discrepancy between the two calibrations would indicate a non-uniformity in depth response within a tower. The source runs must be made with separate, dedicated electronics, since an integration time of 10 ms is needed to measure the DC current induced by the source.

There are three sets of data for each module which must be kept in a data base and cross-referenced. These are the phototube gain data (LED), the cosmic ray calibration data, and the source data. These will eventually be used with both the test beam data on one module, and the calibration in place in STAR from many physics processes.

Cosmic ray tests at the assembly sites will additionally study the response of individual layers in the towers. Special optical connectors will be used to break out the output light from individual layers and send it to separate photo tubes. This test will be documented and serves as the principal quality assurance measure to verify the required layer-to-layer uniformity is being met in each tower in the production modules.

IV.5.6 Source

The distribution of energy in the layers of scintillator in a lead/scintillator sampling calorimeter can be crudely approximated by the energy distributed by a radioactive source near the shower maximum for EM showers. This method makes the source particularly useful for calibration in that the weighting given to each layer resembles the weighting it has in measuring physical events.

The individual strengths of a radioactive source can be measured adequately, to a percent or two, with simple means. This measurement allows absolute calibration of all modules when only a few have been calibrated in a test beam assuming the fiber systems are in uniformly good condition.

The source system is primarily intended for use off-line in conjunction with test beam studies and/or cosmic ray calibrations. A simple mechanical system pushes the source through thin stainless steel tubes imbeded at 7 radiation lengths in the module. The source motion is continuous and logged by a PC which also integrates the DC current from each of the PMT's. If needed, the source system can be mounted on the module while it is installed in STAR.

Error in the source calibration may come from:

- the dark current in the phototubes. We expect roughly 400 na from the source and roughly 2 na from the dark current, with some tubes having more dark current. (We have measured a factor of 4 increase in dark current in raising the phototube temperature from 23 deg C to 33 deg C.)
- the range of gammas from ^{60}Co has tails larger than a tower size. The peak seen will depend slightly on the width of the tower and because the towers are exactly projective, they have different linear dimensions. We can both sum and compare adjacent towers to control this effect.
- position of the source in the source tube with respect to the scintillator and lead changes the solid angle and intermediate absorber slightly. We use a small source and a small tube to minimize this effect (_ 1 mm diameter).

Estimate of Source Strength for STAR EMC Calibration

^{60}Co has two gamma rays per decay, one about 1.17 MeV and one about 1.33 MeV. The absorption length in Pb and scintillator are both about 10 grams/cm^2 at about 1 MeV. This means we can calculate the energy deposition just from the mass. Also, it gives about 1/2 of the gammas absorbed per Pb-Scint pair. So the attenuation goes like 1/2, 1/4, 1/8, 1/16 in calorimeter layers. Assuming a PMT gain of 2×10^5 we estimate that a 1 mCi source will produce approximately 400 nA DC current which is readily measurable at the 1% or better range. PMT dark currents are expected to be approximately 2 nA but could easily vary from near zero to 10 nA from tube to tube. We will measure the individual tube dark currents before and after source runs to permit subtraction.

IV.5.7 Conversion Electrons

Electrons are used to tie the EMC calibration of each tower to measurements of magnetic field and track curvature. An abundant source of electrons is conversions of gammas from _^{o}'s in the beam pipe and the SVT. This material constitutes about 5% of a radiation length. The resolution of the calorimeter and the tracking are comparable at about 15 GeV if the vertex is used in fitting the track. The means of the E versus p distributions can be found very well at higher energies if a number of events are used in the analysis. When using electrons from either physics at the vertex or conversions of gammas, we depend on the TPC plus Magnet plus vertex calibrations to do our energy calibration.

We can also use conversion electrons to set the relative scale between calorimeter and shower max. and between calorimeter and Pre-shower.

IV.5.8 Two Body Decays

Very good calibrations of both the EMC and tracking detectors can be done with $e^+ e^-$ decays of particles of definite mass such as J/ψ and Z^o. The EMC can also be calibrated with 2 photon decays such as π^o or η. The energy range for these 2 photon calibrations is restricted to be low enough that the spatial separation measurement in the SMD can be made with the precision of the desired energy measurement.

IV.5.9 Electronics and Charge Injection

Electronics cards for PMT, SMD, pre-Shower, and trigger shall be calibrated electronically, independent of the detector, so that they are interchangeable. If the pedestals and gains and linearities are not sufficiently uniform on all cards, then a record will be kept that travels with each card. We want to make it easy to exchange cards because we do not want to lose calibration for large numbers of EMC channels when part of one card with many channels fails.

Different cards will be used in both the test beam and cosmic ray calibration set-ups than in the calorimeter in place, so the scales must be measured and documented.

Some aspects of electronic calibration are:

1) Charge injection on PMT cards.

2) Voltage signal on SMD cards, and charge injection of preamplifiers.

IV.6 EMC calibration data sets

We define the EMC calibration data sets for use in the STAR data stream and storage. Simple ASCII files of numbers for the following are sufficient. We should include text headers and comments inside these files. Note also that there may be multiple historical versions of the data sets to be saved for cross checking, to see how the system changes in time. There is extensive documentation in STAR concerning the read-in times required for EMC calibration, and the amount of computer analysis required.

INPUT CALIBRATION DATA SETS	APPLICATION CALIBRATION DATA SETS
PMT	PMT data collector ped. sub.
--------------------------------------	Trig LVL 0 pedestals and gain
cosmic ray	SMD data collector ped. sub.
(1 gain + 1 ped) * (4800 + 720)	
source	PMT ped, gain LVL 3
(1gain+1ped+1dark-c.) *(+)	
(multiple sets)	
LED	SMD ped, gain LVL 3
(1 gain + 1 ped) * (4800 + 720)	
(multiple sets)	
pion/muon no TPC	PMT offline
(1 gain + 1 ped) * (4800 + 720)	
(multiple sets)	
pion/muon with TPC	SMD offline
(1 gain + 1 ped) * (4800 + 720)	
(multiple sets)	
charge injection - card	PRE-SHR LVL 3
(1 gain + 1 ped) * (4800 + 720)	
test beam	PRE-SHR offline
(1 gain + 1 ped) * (4800 + 720)	
pi-0 recon mass	Pre-SHR collector ped. sub.
(1 gain + 1 ped) * (4800 + 720)	
eta recon mass	
(1 gain + 1 ped) * (4800 + 720)	
J/psi-recon mass	
(1 gain + 1 ped) * (4800 + 720)	
electron mom in TPC	
(1 gain + 1 ped) * (4800 + 720)	

SMD |
--------------------------------------- |
charge injection-card |
(1 gain +1 ped)*(30k + 10k) |
test beam |
(1 gain +1 ped)*(30k + 10k) |
pre-amp bench calib |
(1 gain)*(30k + 10k) |
capacitances? |
pi-0 recon mass |
(1 gain + 1 ped) * (30k + 10k) |
eta recon mass |
(1 gain + 1 ped) * (30k + 10k) |
J/psi-recon mass |
(1 gain + 1 ped) * (30k + 10k) |
electron mom in TPC |
(1 gain + 1 ped) * (30k + 10k) |
|
|
PRE-SHOWER |
------------------------------------- |
cosmic |
(1 gain + 1 ped)*(4800+720) |
led |
(1 gain + 1 ped)*(4800+720) |
pion/muon no TPC |
(1 gain + 1 ped)*(4800+720) |
pion/muon with TPC |
(1 gain + 1 ped)*(4800+720) |
charge injection-card |
(1 gain + 1 ped)*(4800+720) |
test beam |
(1 gain + 1 ped)*(4800+720) |
pi-0 recon mass (in EMC twr) |
(1 gain + 1 ped) * (4800 + 720) |
eta recon mass (in EMC twr.) |
(1 gain + 1 ped) * (4800 + 720) |
J/psi-recon mass (in EMC twr.) |
(1 gain + 1 ped) * (4800 + 720) |
electron mom in TPC |
(1 gain + 1 ped) * (4800 + 720) |

|
OLD Application Data Sets |
to be adjusted |
-------------------------------------- |

3 sets (PMT,SMD,PRE) |
each in 3 formats |